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United States Climate Reference Network (USCRN)

Functional Requirements Document

July 2007

Prepared by:

U.S. Department of Commerce
National Oceanic and Atmospheric Administration (NOAA)
National Environmental Satellite, Data, and Information Service (NESDIS)

NOAA/NESDIS
CRN Series
X040

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Preface

This document comprises the National Oceanic and Atmospheric Administration (NOAA)/National Environmental Satellite, Data, and Information Service (NESDIS) Revision 1 baseline publication of the *United States Climate Reference Network (USCRN) Functional Requirements Document* (version DCN 1, July 13, 2007, publication). The document number is NOAA-CRN/OSD-2003-0009R1UD0.

This document describes the functional and system performance requirements for the USCRN, how well the system must perform, and under what conditions the system must operate and survive. Requirements are identified for measurement parameters, communications, data processing, access, and archive for the USCRN system. Detailed system specifications are not addressed in this document nor are specific hardware, software, or communications solutions maintenance requirements.

This revision reflects site location implementation improvements which provide higher accuracy for measuring vertical distance Above Sea Level (ASL). The National Climatic Data Center (NCDC) will improve site elevation accuracy for USCRN sites to 6 meters from the previous 15 meters.

The publication of this baseline document closes the following Document Configuration Change Request:

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NOAA/NESDIS acknowledges the efforts of the NOAA/NESDIS NCDC and Short and Associates, Inc., for their preparation of the material in this document.

Future updates and revisions to this document will be produced and controlled by NOAA/NESDIS.

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Section 1.0 Introduction

1.1 CRN Objective

The objective of the United States Climate Reference Network (USCRN) is to measure, record, and report with the highest possible quality a thoroughly documented set of surface environmental observations, representative of the climate of the United States. The CRN will provide future long-term (50-100 years) high-quality observations that can be coupled to past long-term observations, and be adequate to meet the exacting demands of climate science. Reliable observations from the CRN will allow the detection of present and future climate change, and enable scientists to increase our understanding of natural and human-induced effects.

1.2 Purpose

The purpose of this Functional Requirements Document (FRD) is to present operational and performance requirements for the CRN, a highly automated climate observing system. This document provides the necessary foundation for subsequent system specifications as well as operational and support requirements documents.

1.3 Scope

This document describes the functional and system performance requirements for the CRN, how well the system must perform, and under what conditions the system must operate and survive. Requirements are identified for measurement parameters, communications, data processing, access, and archive for the CRN system.

This document does not address the following aspects of the deployed CRN system:

- Detailed system specifications
- Specific Hardware, Software, or Communications Solutions
- Maintenance Requirements.

1.4 Document Organization

The *USCRN Functional Requirements Document* is organized as follows:

- Section 1 Introduction
- Section 2 CRN Overview
- Section 3 Field Site Functional Requirements
- Section 4 Network Communications Functional Requirements
- Section 5 NCDC Functional Requirements
- Section 6 CRN Availability Requirements
- Section 7 Documentation Requirements

1.5 References

A. *Guide to Instruments and Methods of Observation*, Geneva, Switzerland (WMO, 1996, Doc 8).

B. *Federal Standard Definitions for Meteorological Services and Supporting Research*, FCM-S1-1981, Federal Coordinator for Meteorological Services and Supporting Research.

Section 2.0 CRN Overview

2.1 CRN System Summary

When fully implemented, the CRN will provide observations from approximately 300 locations. Each location will be carefully selected to capture the representative climate regions of the nation. A communications network will link each location to the National Climatic Data Center (NCDC), where the observations will be quality controlled, archived, and made readily available with their metadata to a worldwide clientele.

2.2 CRN Unique Service Requirements

The CRN will have data that extend over 50-100 years; accuracy tied to irrefutable standards (calibrations traceable to National Institute of Standards and Technology [NIST] standards); extensive site/system documentation; routine instrument upgrades; a rigorous maintenance program; periodic instrument recalibration and/or replacement; and, when a new instrument is introduced, a mandatory one-year minimum of parallel operation with the baseline instrument for comparison at each affected site.

2.3 CRN Field Sites

Each CRN field site will record surface measurement data, compute derived values, and periodically report these values to NCDC. For each parameter, the frequency with which the raw data are recorded will be sufficient to ensure that the computed values are fully representative of each collection period. Example-derived values include maximum, minimum, averages, and standard deviations.

2.4 CRN Communications Network

The CRN will include a network communications component to connect each field site to NCDC. The network communications component will have the capacity to reliably provide the data and information from all CRN field sites to NCDC.

2.5 NCDC, the CRN Central Facility

NCDC is the “hub” of the CRN and serves as the interface between the field sites and the users of the CRN data. CRN data will flow from the network communications central interface to NCDC’s processing and storage infrastructure, and be posted to the web accessible CRN database for direct on-line access. NCDC will maintain CRN documentation on line, and use automated data quality control processes to automatically detect the need for maintenance at field sites.

Section 3.0 Field Site Functional Requirements

3.1 Operating Environment

CRN field sites will be deployed in a wide variety of climatic regimes and are required to operate virtually unattended (minimum human presence) for prolonged periods of time. They shall operate dependably while experiencing extremes in temperature, humidity, wind, precipitation (liquid and frozen), and other environmental factors. With the exception(s) stated below, the CRN field site shall operate as specified over the following environmental range:

Temperature	-60 to +60^{0}C
Relative Humidity	to 74% at 35^{0}C; to 100% at 27^{0}C
Wind	to 50 meters per second
Rain	to 30mm per minute
Freezing Rain	25mm per hour with 9 meter per second wind
Dust	Exposure to dust laden environment
Sunshine	1400 Watts per square meter at 50^{0}C
Altitude	-500 to +10,000 feet

Exception: The CRN precipitation sensor is required to operate as specified over the temperature range of -25 to +60^{o}C.

3.2 Parameter Requirements

This section describes the initial climate observing requirements in terms of the specific parameters to be measured; measurement accuracies, ranges, and resolutions; and computed values to be reported. The installation of sensors will be guided by the recommendations in the World Meteorological Organization (WMO), 1996: *Doc 8, Guide to Instruments and Methods of Observation*, Geneva, Switzerland (Reference A), i.e. sensors to be installed 1.5 meters above the surface of the ground. In places where there is significant snow on the ground during the winter months, sensors (bottom of the aspirated temperature shield) are to be installed at a height of 0.6 meters [two (2) feet] above the surface of the average maximum snow depth or 1.5 meters [five (5) feet] above the surface of the ground (no snow), whichever is higher. The 1.5 meters height is also consistent with the recommended height for the Automated Surface Observing System (ASOS), Automated Weather Observing System (AWOS), and U.S. Cooperative Observing Network (COOP). In all cases, safety considerations for personnel installing and maintaining the equipment and sensors must always be taken into account when designing the physical arrangement of the instrument suite.

Except for ground surface (skin) temperature, the definitions used in this section can be found in the Federal Standard Definitions for Meteorological Services and Supporting Research, FCM-S1-1981, published by the Federal Coordinator for Meteorological Services and Supporting Research (Reference B).

3.2.1 Primary and Supporting Measurements

The primary CRN measurement parameters are air temperature and precipitation accumulation. Measurement of these two parameters is essential for the climate record, and is required at all CRN field sites. The supporting or secondary measurement parameters are wind speed, solar radiation, and ground surface (skin) temperature. (Candidate parameters for future addition include relative humidity, soil moisture, and soil temperature.) The supporting or secondary parameters contribute to improving the confidence in the observational measurements, and provide insight into the reliability and performance of the primary sensors by means of a "gross error cross check" between the various parameters measured and reported. For instance, wind speed measured in the vicinity and near the height of the precipitation gauge orifice provides useful data when reconciling total precipitation accumulations recorded under windy conditions. The supporting parameters provide concurrent information about the environment in the immediate vicinity of the field site, and aid the development of inter-site and inter-network transfer functions. The development of such transfer functions will provide a statistical relationship between measurements at a CRN site and similar measurements taken by other sites and other surface observing networks. The transfer functions are critical for examining changes in the climate signal from and among different observing sites and networks, and will more effectively and more confidently quantify the uncertainty among them. Collecting secondary parameter data will also support new and on-going research endeavors regarding the interrelationship between surface wind speed, global solar radiation, radiative surface (skin) temperature, and air temperature.

3.2.2 Calibration of Sensors

CRN sensors shall be calibrated against existing and recognized (traceable) calibration standards. Standard methods of calibration endorsed by the NIST will be followed to the greatest extent possible by the CRN Program. For cases in which no documented NIST standards exist, alternative calibration and testing procedures can be used if documented and accepted as standards by the scientific community. Calibration procedures and standards employed will be documented. Calibration results of each sensor will be documented and available as part of the station history files.

3.2.3 Raw Data Sample Rates and Hourly Reports

The following paragraphs specify the calculated or derived values to be reported for each parameter. Calculated or derived values include averages, maximums, and minimums over specified measurement periods. The actual raw data sample rates are not specified, and are to be considered in conjunction with the time constant or responsiveness of the sensors themselves.

3.2.3.1 Sample Rates

For each parameter, the frequency with which the raw data is recorded shall be sufficient to ensure that the computed values are accurately representative of each collection period.

3.2.3.2 Hourly Reports

Where calculations are based on an hour's data, the period shall begin on the hour. Hourly data are critical for QA/QC, network performance, and to quantify the uncertainty in daily and monthly USCRN datasets. The transmission frequency and schedule is required to be programmable at each field site (see Section 3.3.2). Each hourly report shall identify the associated measurement period.

3.2.4 Air Temperature

Each CRN field site shall provide air temperature measurements. Each air temperature sensor and its supporting apparatus shall be configured to accurately reflect the ambient air temperature at the site. Provisions to eliminate exposure to precipitation and minimize measurement biases caused by solar heat loading are required.

Air temperature measurements shall meet the following requirements:

Minimum Accuracy	$\pm$ 0.3^0 C over the range -50 to $+50^0$ C $\pm$ 0.6^0 C over the ranges -50 to -60^0 and +50 to -60^0C
Resolution	0.01^0 C for the raw data 0.1^0 C for the computed five minute averages
Reported Values for Each Sensor	- Maximum hourly value (largest 5 minute average) - Minimum hourly value (lowest 5 minute average) - Average of each hour's twelve 5-minute averages - Average temperature of the hour's last five minute period

3.2.5 Precipitation

Each CRN field site shall provide precipitation measurements. For liquid precipitation, each CRN field site shall measure the vertical depth of precipitation which reaches the Earth's surface for each 15-minute interval during an hour. This is necessary to compare with existing networks and quantify possible extreme events. For frozen precipitation, each CRN field site shall measure the water equivalent depth (depth if the precipitation were in a liquid state) which reaches the Earth's surface for each 15-minute time interval. Each precipitation sensor and its supporting apparatus shall be configured to accurately reflect the precipitation (or water equivalent) accumulation in the area of the field site. Provisions to minimize both the positive and negative effects of local winds on the precipitation measurements are required.

Precipitation measurements shall meet the following requirements:

Accuracy	± 0.25 mm or ± 2% of the reported value, whichever is greater.
Minimum Capacity	600 mm.
Maximum Required Precipitation Measurement Rate	30 mm per minute
Minimum Reporting Resolution	0.25 mm.
Reported Values for Each Sensor	Precipitation accumulation value for each 15 minute period

3.2.6 Wind Speed

Each CRN field site shall provide wind speed measurements, taken from the height of the temperature sensor. Wind Speed measurements shall meet the following requirements:

Minimum Accuracy	±1 meter per second, or ±2% of the measured value, whichever is greater
Threshold	≤ 1 meter per second
Resolution for Raw Data and Reports	1 meter per second
Reported Values for Each Hour	Hourly average wind speed

3.2.7 Global Solar Radiation

Each CRN field site shall provide global solar radiation measurements. Global solar radiation is the combination of both direct and indirect (scattered or diffusely reflected) radiation falling together on a horizontal surface. Global solar radiation measurements shall meet the following requirements:

Minimum Accuracy	±70 Watts per square meter.
Minimum Resolution	10 Watts per square meter.
Reported Values for Each Hour	Hourly average value

3.2.8 Ground Surface (Skin) Temperature

Each CRN field site shall provide ground surface temperature measurements. Ground surface, or skin temperature is the effective radiative temperature of the ground surface.

Ground surface temperature measurements shall meet the following requirements:

Minimum Accuracy	$\pm 0.5^0$C.
Minimum Resolution	0.1^0C for the raw data and reported values
Reported Values for Each Hour	Hourly average value

3.2.9 Relative Humidity

CRN field sites should be installed so that relative humidity measurements can be accommodated without system redesign. Relative humidity is the ratio of the actual vapor pressure of the air to the saturation vapor pressure at the air's current temperature. The sensors used to produce raw data for relative humidity, and their supporting apparatus, shall be configured to accurately reflect the ambient air at the field site. Provisions to eliminate exposure to precipitation and minimize measurement biases caused by solar heat loading are required.

Relative humidity measurements shall meet the following requirements:

Minimum Accuracy	$\pm$ 3% over the range from 10% to 90% $\pm$ 5% below 10% and above 90%
Minimum Resolution	1% for the raw data and reported values
Reported Values for Each Hour	Average relative humidity over the hour.

3.2.10 Soil Moisture and Temperature

Reserved

3.3 Field Site Processing Requirements

3.3.1 Introduction

This section presents the functional requirements for data processing, storage, recovery, and similar functions required at each CRN field site. These processing requirements are in addition to the computation requirements stated in Section 4.2, which included calculation of averages, minimums, maximums, and other parameters.

3.3.2 Local Programming Capability

Each CRN field site shall provide local programming capabilities to include incorporation of new and revised processing algorithms, modification of sensor sample rates, addition of new sensor types, modification of transmission frequency, and modification of output message format.

3.3.3 Automatic Recovery

Should a field site lose power and the local batteries become depleted, the site shall automatically return to full operating condition within one hour following restoration of site power.

3.3.4 Site Monitoring

Each CRN field site shall transmit engineering information to provide early insight into conditions that may effect sensor measurements or require on-site maintenance. Examples of such engineering information include battery voltage and aspirated shield fan motor rotations per minute (rpm).

3.3.5 Sensor Ports

A representative CRN field site is anticipated to include an initial complement of up to 12 sensors. To accommodate both new sensor types and comparison testing, each CRN field site shall include a sufficient number of sensor interface ports to accommodate 18 sensors.

3.3.6 Security

Each CRN field site shall incorporate reasonable security provisions to prohibit unauthorized access and/or modification.

3.3.7 Data Storage

Observational Data: Each CRN field site shall store its measurements for a minimum of sixty days, in order that these data will not be lost when communications or specific processing functions are not operating correctly.

Report Information: Each CRN field site shall store its required report information for a minimum of 60 days.

3.3.8 Retrieval of Stored Data and Information

Each CRN field site shall provide an interface for local electronic extraction of any and all data and information required to be stored. This includes processing algorithms, measured observational data, computed parameters, and engineering information.

3.3.9 Processing and Storage Margin

Each CRN field site must be able to accommodate revised or additional algorithms, computation and storage of additional parameters, and increased data sample rates. Each site shall provide a minimum of 50% processing and storage margin above that necessary to support the initially installed configuration.

Section 4.0 Network Communications Functional Requirements

The CRN communications network includes the network interface device at each field site, the inclusive network transmission medium and infrastructure, and the central interface at NCDC.

4.1 Initial Performance

The CRN communications network shall have sufficient capacity to provide NCDC with the required data and information from 300 field sites within one hour.

4.2 Intermediate Storage

The CRN communications network shall retain observations from all CRN field sites. This retention is required to mitigate the effects of a temporary outage of the NCDC central interface or of the connection between NCDC and the CRN communications network. The communications network shall retain each collected observation until successful receipt at NCDC is acknowledged or for 24 hours, whichever is smaller.

4.3 Expansion Capacity

The CRN communications network shall have sufficient expansion capacity to accommodate a 200% increase to the initial field site message size from each of the 300 field sites.

Section 5.0 NCDC Functional Requirements

5.1 Introduction

NCDC is the central collection facility of the CRN, and serves as the interface between the field sites and the users of the CRN data. The Central Facility will ingest and process the reports from all CRN field sites, and make CRN products available to a worldwide clientele. Ingest, inventory, quality control, maintenance initiation, and long-term stewardship of the CRN observations will become part of the routine base activities at NCDC.

5.2 Ingest, Processing, and Storage

5.2.1 Ingest

The Central Facility shall ingest CRN reports immediately upon their arrival from the communications network central interface. Ingest shall include a highly automated "rule-based" inventory and shall report the completeness of reporting sites and parameters for each reporting cycle.

5.2.2 Processing

Central Facility processing shall incorporate automated quality control (QC) processes to detect malfunctioning sensors and support equipment, engineering information approaching predetermined thresholds, and suspect observational values. All resultant indications or "flags" shall be reported for each CRN reporting cycle.

5.2.3 Storage

The Central Facility shall place observational data, assigned QC flags, all metadata, and site station history into the NCDC permanent archive and access system. Format, design, and documentation will be in accordance with the NCDC "best access and archive practices" utilized for similar databases.

5.2.4 Data Access

NCDC shall provide timely access to the CRN data, station history, and all other documentation to a worldwide clientele. All CRN observational data, attached respective "flags", metadata, and all documentation shall be posted to the web-accessible CRN database for direct on-line access. Provisions for concurrent access, user presentation, and performance shall be in accordance with NCDC best practices.

5.3 Initiate Maintenance

The Central Facility inventory, quality assurance, and quality control processing system shall generate automated notifications to designated maintenance personnel. Automated notifications shall be provided when a site report is indicative of an anomaly.

Section 6.0 CRN Availability Requirements

6.1 Field Site Availability

CRN field sites will be deployed in a wide variety of climatic regimes and required to operate virtually unattended for a prolonged period of time. Site components shall operate dependably while experiencing extremes in temperature, humidity, wind, precipitation, power anomalies, and other environmental factors. The exposed sensors, data processor, batteries, communications device, and associated support equipment shall meet robust operational and survival environmental requirements. The primary role of each CRN field site is to report the required air temperature and precipitation information. Other required functions, while important, are secondary to this primary role.

6.2 Availability of Air Temperature and Precipitation Reports

Under normal operations, the communications network will deliver each CRN field site's required air temperature and precipitation reports to NCDC in accordance with the transmission schedule. Should a site's reports not be provided to NCDC in accordance with the transmission schedule, due to intermittent or prolonged equipment or communications outages, appropriate secondary delivery methods may be used to provide delayed reports to NCDC. Each CRN field site's required air temperature and precipitation reports shall be delivered to NCDC within 30 days after the close of the month of observation with a minimum availability of 97%, and in accordance with the transmission schedule with a minimum availability of 95%. In support of these availability requirements where multiple sensors are installed for either or both of these two parameters, a majority of the sensors for each parameter shall be operating within specification, as well as all processing, storage, and output (to the network local interface) functions associated with the required reports.

6.3 All CRN Functions

All CRN field site and communications network functions associated with the delivery of air temperature and precipitation reports to NCDC shall operate in support of the availability requirements specified in Section 6.2. All other required CRN functions shall operate with a minimum availability of 90%.

Section 7.0 Documentation Requirements

7.1 Introduction

CRN data users need to know everything about how a measurement is taken and how the resulting reported observational values are computed. The CRN program will provide this information in Station History Files and CRN Central Processing Documentation.

7.2 Station History Files

Station history files shall contain complete information on each CRN field site. Although sites will be deployed with the same sensors, support equipment and physical configuration to the extent practical, each site will be unique in a number of respects upon deployment. Over time, differences among sites may expand and up to date information on each site must be kept current.

7.2.1 Site Location

The accuracy of the site's coordinates will be within plus or minus 15 meters for latitude, longitude, and 6 meters for elevation (above or below sea level).

7.2.1.1 Latitude/Longitude Accuracy

The accuracy that can be obtained with the existing GPS system (Garmin Legend C) utilized by the USCRN program is plus or minus 15 meters for latitude, longitude.

7.2.1.2 Elevation Accuracy

The measurement of elevation with a GPS unit (via the pressure sensor) that does not utilize the Wide Area Augmentation System (WAAS) is about 20 feet, which is equivalent to 0.02" Hg. This can be accomplished only if the GPS is allowed about one hour to stabilize. The USCRN does not use the GPS unit to obtain elevation at a particular site. Instead, USGS maps that adhere to the National Map Accuracy Standard are used. This standard stipulates that 90% of elevations sampled be within +/- half the distance of the contour. In most cases, a minimum of 20-foot contours is obtainable. The exception might be coastal areas, which could have five-foot contours.

A GPS system that utilizes the WAAS can provide a higher accuracy for horizontal and vertical distance. The worst-case accuracy is within 7.6 meters of the true position 95% of the time. This is achieved via a network of ground stations located throughout North America that monitor and measure the GPS signal. Measurements from the reference stations are routed to two master stations that generate and send the correction messages to geostationary satellites. These satellites broadcast the correction messages back to Earth, where WAAS-enabled GPS receivers apply the corrections to their computed GPS position.

7.2.2 Local Terrain

Station history files shall include a description of any aspects of the local landscape that may affect the quality of the observations taken and reported. Any changes to the surroundings must be thoroughly described, dated, and included in the station history files within seven working days after the completion of the activity. Station history files shall include up-to-date digital photographs of the instrument site and the surrounding terrain. Where practical, satellite images of the site will be a part of the station history files.

7.2.3 Sensor Complement

Station history files shall identify the current sensor complement at each site. Detailed specifications of each sensor shall be readily available to users, either as part of the station history files or as part of the CRN system documentation.

7.2.4 Field Site Processing Algorithms

Station history files shall contain, or identify a readily available reference to, each processing algorithm inherent to or associated with each sensor and reported value. This information shall include sampling rates and all computation algorithms.

7.2.5 Calibration History

For each site, the station history files shall include the calibration history of each sensor. This information shall include the date and the results of each sensor calibration.

7.2.6 Equipment Failure Records

Station history files shall identify each site's equipment failures, how each failure was detected, and the corrective action taken. The date and time of each failure and correction shall be included.

7.2.7 Maintenance Record

Station history files shall describe all maintenance and changes to each site.

7.3 CRN Central Processing Documentation

CRN data users need to know how the data reported by each field site are processed by the central facility, and how this may affect the data that are made available.

7.3.1 Quality Control Processing

The central processing documentation shall include a general description of the quality control processing and the meaning of each flag. The detailed quality control software code shall be made available to users.

Appendix A. Acronyms and Abbreviations

ASL	Above Sea Level
ASOS	Automated Surface Observing System
AWOS	Automated Weather Observing System
COOP	Cooperative Observing Network
CRN	Climate Reference Network
FRD	Functional Requirements Document
GPS	Global Positioning System
QC	Quality Control
rpm	rotations per minute
NCDC	National Climatic Data Center
NESDIS	National Environmental Satellite, Data, and Information Service
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
USCRN	United States Climate Reference Network
WMO	World Meteorological Organization

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